Determination of the Stress State of the Body of a Hopper Car Transported by Sea

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Determination of the Stress State of the Body of a Hopper Car Transported by Sea

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Abstract

The work deals with the special features of the loading on the body of a hopper car transported by a train ferry. It has been found that the maximum stresses in the body of a hopper car exceed the normative values in the standard lashing diagram. This can endanger the stability of a vehicle on the train ferry and the stability of the sea vessel.
The safe transportation of a hopper car by sea can be ensured by means of improvements in its structure, i.e. fastening units for the chain binders. The rigidity of the bolster beam in the fixing points of these fastening units can be ensured with reinforcing diaphragms. The effectiveness of the proposed constructive improvement is confirmed by theoretical calculations. The results of the research will be of value for those who are concerned with the safe transportation of rail cars by sea.
KEY WORDS: *hopper car, inertial loading, strength of the body, stress state of the body, rail-ferry service*

1. Introduction

One of the criteria of good economic performance in European countries is the coordinated operation of the whole transportation system. And so far the railway transport has played the leading role and provided the transportation process both independently and collaboratively with other types of transport, thus forming combined transportation systems. Therefore the countries with an access to sea are developing train ferry transportation.

Apart from considerable advantages this type of transport has an important disadvantage, i.e. poor technical adjustment of rail vehicles to sea transportation. Due to a lack of special structural elements, rail cars are secured on the deck with the structural elements that are not designed for it. This can cause damage to the components of the rail cars, break their stability on the deck and pose a risk to the stability of the train ferry. Therefore, there is a need to research into customization of the construction of rail vehicles for transportation by sea.

2. Analysis of Publications

The issues of the loading and the strength of transport vehicles transported by sea have been studied by many specialists. The effect of the center of gravity of a transport vehicle on the equilibrium of a vessel is considered in [1]. The authors presented the methodology for estimation of the effect of the center of gravity of a vehicle on the vessel equilibrium. The research was made by the example of a modular vehicle placed on the container carrier. However, the researchers did not use this algorithm for a rail car.

The designing of advanced car construction are described in [2, 3]. The authors presented the spatial models of the construction of rail cars and the results of the stress state calculation. However, the designing of these rail car structures did not include forces occurring during transportation by a sea.

Study [4] details the special features of designing the body of a new-generation rail vehicle. One of the special structural features is the use of innovative materials, particularly, extruded aluminium panels. The body structure proposed is lower by mass and keeps the required strength.

The methodology of the multi-scale designing and optimization of innovative lightweight structures of hopper cars are described in [5]. It is based on the North American Standards. The design proposed was proved through comparison the results of computer modelling and those obtained from accurate analytical equations. In [4, 5] the authors did not research the issue of customization of the rail car structures proposed to the transportation by train ferries.

Study [6] describes the results of research of the loads on the construction of a rail car. But the authors used only the normative values of loading on the rail car in operation. The study also presents the results of stress state modelling for the construction of a rail car. However, the designing of these rail car structures did not include forces occurring during transportation by a train ferry.

The inertial loading of an open car placed on a deck is considered in [7]. The study presents the results of stress state calculation for the car frame during new fastening. The authors believe that the strength of a car can be improved by means of viscous binders used for securing it on the deck.

The designing of the bearing structures of rail cars used for operation on main lines and for train ferry transportation is substantiated in [8]. The research was made for the body of a flat car. However, the authors of studies [7, 8] did not give attention to the technical customization of the bearing structures of some types of rail cars to transportation by sea.

3. Purpose and Main Objectives of the Article

The objective of the research is to determine the strength and propose some improvements in the body of a freight car that will ensure its safe transportation by a sea. The research was made for a hopper car. To do this, the following tasks are allocated:

- to determine the strength of the standard body of a hopper car transported by a train ferry;
- to propose the measures for improvements in the body of a hopper car.

4. The Main Material of the Article

The stress state of the standard body of a hopper car transported by a sea was determined on the prototype of a hopper car Model 20-9749 (Ukraine). This type of a rail car was chosen because it has not yet been studied in terms of determination of the loads when transported by a train ferry.

During train ferry transportation (Fig. 1, a) hopper cars are most frequently secured to the towing shackles (Fig. 1, b). And reusable lashing devices are used.

a b

Fig. 1 Hopper cars transported by a sea vessel: a – rail cars on the sea vessel; b – attaching the hook to the towing shackle

The inertial loads on the body of a hopper car were calculated with the mathematical model that described the rolling motion of a train ferry [9, 10]:

$$I_x \cdot \ddot{q} + \left(\Lambda_\theta \cdot \frac{B}{2}\right)\dot{q} = p' \cdot \frac{h}{2} + \Lambda_\theta \cdot \frac{B}{2} \cdot \dot{Y}(t), \quad (1)$$

where I_x – the inertia moment of a train ferry; Λ_θ – the roll damping coefficient; B – the train ferry breadth; p' – the wind load; h – the train ferry depth; $Y(t)$ – the law of motion of the sea wave.

Hence,

$$I_x = \frac{D}{12 \cdot g}\left(B^2 + 4{z_g}^2\right), \quad (2)$$

where D – the weight displacement; z_g – the coordinate of the gravity center of a train ferry.

The mathematical model included that the car traveled by the trajectory of a train ferry. The research was based on the characteristics of the vessel Geroi Plevny, which serviced the route from Chornomorsk (Ukraine) to Varna (Bulgaria) and from Chornomorsk to Poti/Batumi (Georgia).

The parameters of the disturbing action were taken from reference literature, and for the Black Sea they are as follows: wave height – 8 m, period – 9 s, wind pressure – 1.47 kPa [11].

The mathematical model was solved with the variation method for arbitrary constants [12] at the initial conditions equaling zero [13-15]. It was found that the total value of acceleration to a car placed on the sea vessel was

0.24g.

The acceleration value obtained was included in the stress state determining for body of a hopper car. The graphic model of a hopper car was built in SolidWorks according to its album of drawings.

The strength calculation of the construction of a hopper car was made with the finite element model in CosmosWorks [16-18].

The FEM consisted of tetrahedrons [19, 20]. The model has 376670 elements and 126221 units. The design diagram of the hopper car body (Fig. 2) included the following loads: the vertical static load P_v^{st}, the pressure from the cargo P_p, the wind load P_w, and the loads to the car body through the fastening P_{ch}. Steel 09C2Cu with the linear isotropic properties was used as the structural material.

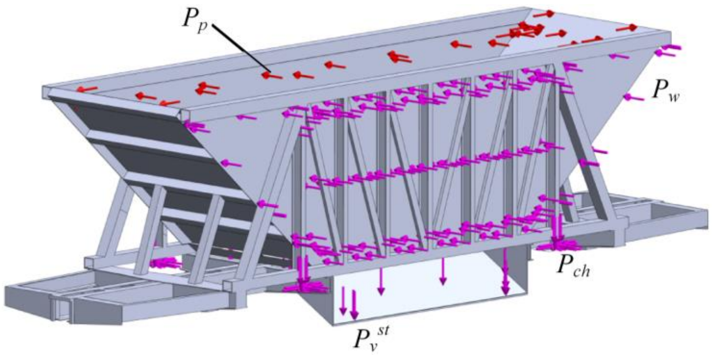


Fig. 2 Design diagram of the body of a hopper car

The stress state of the body of a hopper car are given in Figs. 3 and 4.

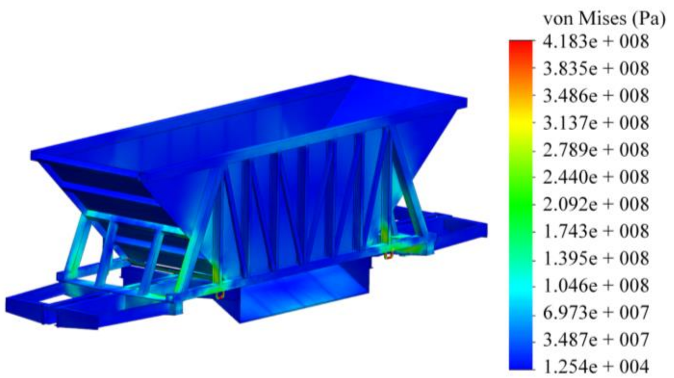


Fig. 3 Stress state of the bearing structure of a hopper car

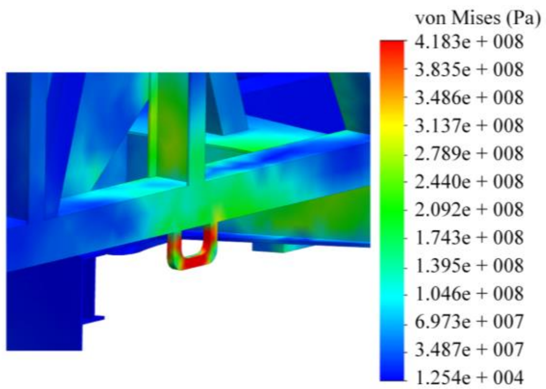
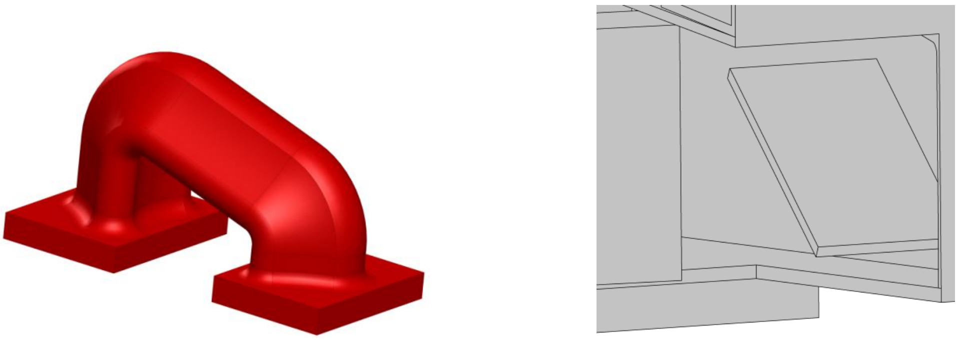


Fig. 4 Stress state of the bearing structure of a hopper car near the towing shackle

The maximum stresses in the body of a hopper car were about 420 MPa and were concentrated in the towing shackle. Thus, in the typical lashing diagram for a hopper car on the deck the maximum stresses in the body above normative values. The normative values included the yield limit of the material equaling 345 MPa [21, 22].

The authors believe that the reliable fastening of the body of a hopper car on the deck can be fulfilled by means of fastening units mounted on the bolster beams (Fig. 5, a); the required rigidity of the bolster beam in the fixing areas of these fastening units can be ensured with inclined reinforcing diaphragms (Fig. 5, b).



a b

Fig. 5 Improvements in the body of a hopper car: a – fastening unit; b – reinforcing diaphragm

The thickness of the diaphragm should be equal to the thickness of the vertical sheet of the bolster beam. The parameters of the fastening unit were calculated with consideration of the dimensions of the bolster beam of a car and those of the hook of a fastening.

The stress state calculation of the construction of the car included the improvements proposed. And the design model (Fig. 6) included the loads identical to those taken in the research of the typical hopper car.

The FEM of the body of a hopper car consisted of 420212 elements and 13787 units.

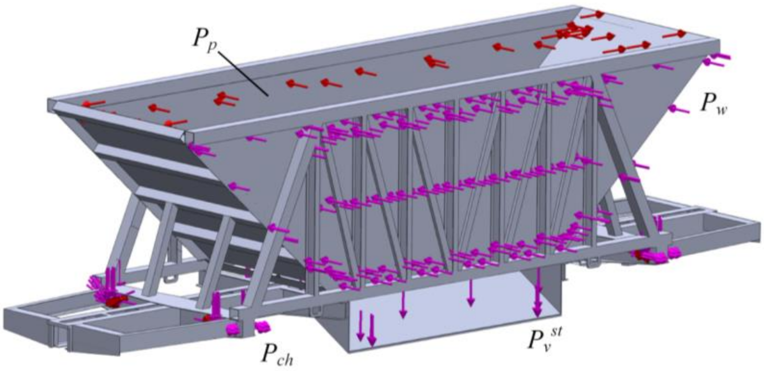


Fig. 6 Design diagram of the bearing structure of a hopper car

The stress state of the body of a hopper car are given in Figs. 7 and 8. The calculation demonstrated that the maximum stresses in the body of a hopper car were about 330 MPa and were observed in the radial part of the unit. Thus, with consideration of the improvements for a car the maximum stresses in its structural elements are within the normative values [21, 22].

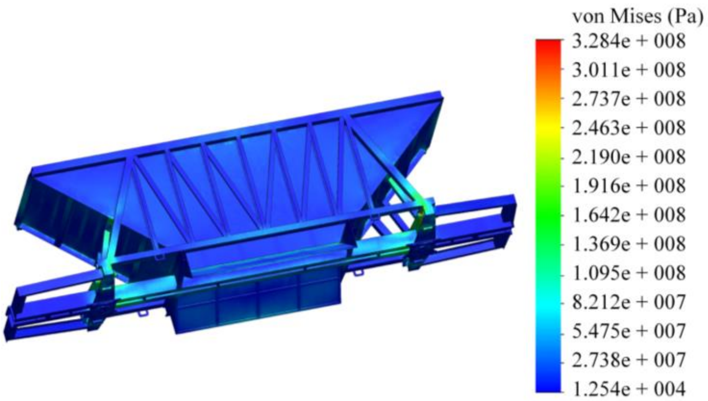


Fig. 7 Stress state of the improved body of a hopper car

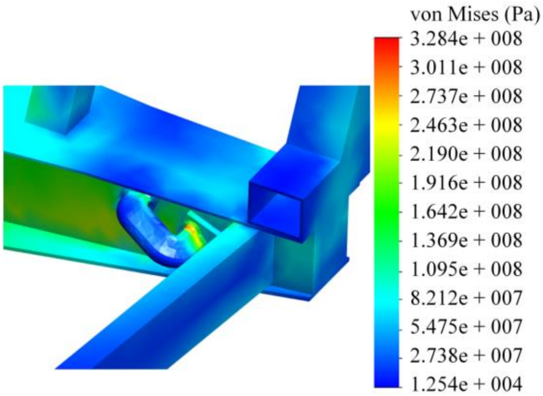


Fig. 8 Stress state of the improved body of a hopper car in the fastening unit

5. Conclusions

The research deals with the determination of the stress state of the body of a hopper car transported by a train ferry. The maximum stresses in the construction of a hopper car were about 420 MPa and were observed in the towing shackle. Thus, in the typical lashing diagram for a hopper car on the sea vessel deck the maximum stresses in the components of the construction exceed the normative values.

The authors have proposed the measures for improvements of the body of a hopper car for its safe transportation by sea. It has been found that the maximum stresses in the construction of a hopper car were about 330 MPa and they were observed in the radial part of the unit. The results of the research will be of value for those who are concerned with the safe transportation of rail cars by sea.

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